

Palomar Testbed Interferometer Observations of Young Stellar Objects

F. P. Wilkin (f.wilkin@astrosmo.unam.mx) *

*Instituto de Astronomía, Universidad Nacional Autónoma de México, Unidad
Morelia, Apdo.Postal 3-72 (Xangari), 58090 Morelia, Michoacán, México*

R. L. Akeson

*Michelson Science Center, California Institute of Technology, MS 100-22,
Pasadena, CA 91125, USA*

Abstract. We present observations of a sample of Herbig AeBe stars, as well as the FU Orionis object V1057 Cygni. Our K-band ($2.2\,\mu\text{m}$) observations from the Palomar Testbed Interferometer (PTI) used baselines of 110m and 85m, resulting in fringe spacings of $\sim 4\text{ mas}$ and 5 mas , respectively. Fringes were obtained for the first time on V1057 Cygni as well as V594 Cas. Additional measurements were made of MWC147, while upper limits to visibility-squared are obtained for MWC297, HD190073, and MWC614. These measurements are sensitive to the distribution of warm, circumstellar dust in these sources. If the circumstellar infrared emission comes from warm dust in a disk, the inclination of the disk to the line of sight implies that the observed interferometric visibilities should depend upon hour angle. Surprisingly, the observations of Millan-Gabet, Schloerb, & Traub 2001 (hereafter MST) did not show significant variation with hour angle. However, limited sampling of angular frequencies on the sky was possible with the IOTA interferometer, motivating us to study a subset of their objects to further constrain these systems.

Keywords: Optical Interferometry, Young Stars, Circumstellar Matter

1. INTRODUCTION

Near-infrared, long baseline interferometry is sensitive to the distribution of dust around the nearest young stars on scales of the order of 1 AU, and provides a powerful probe of models of disks and envelopes of such stars. The Herbig Ae-Be stars are pre-main sequence, emission line objects that are the intermediate mass ($1.5 - 10\,M_{\odot}$) counterparts of T Tauri stars (Hillenbrand *et al.* 1992). We also observed the FU Orionis object V1057 Cyg, expected to have a strong disk signature due to the high accretion rate of such objects. While the evolutionary status of the FU Orionis objects remains unclear, they are believed to be T Tauri stars undergoing an episode of greatly increased disk accretion, involving a brightening of ~ 5 magnitudes. V1057 Cyg, whose outburst began in 1969-70, is the only FU Orionis object for which a pre-outburst

* Partially supported by NSF International Researchers Fellows Program



spectrum is available, confirming its pre-main sequence nature (Grasdalen 1973). Until now, only one FU Orionis object, FU Orionis itself, has been resolved by long baseline optical interferometry (Malbet *et al.* 1998), and V1057 Cyg was chosen for study as the next-brightest such object accessible to PTI.

2. SOURCE SELECTION AND OBSERVATIONS

We selected a sample of 5 sources from the thesis of Millan-Gabet, chosen to satisfy the observing limitations of PTI, and to avoid known binaries (with the exception of MWC 147, whose companion is too faint to affect the current measurements). Details of the instrument are described in Colavita *et al.* 1999. Table I describes our final sample.

Table I. Observing Sample

Name	Alternate	RA (2000.0)	Dec (2000.0)	m_V	m_K	Spec	d, pc
HBC 330	V594 Cas	00 43 18.260	+61 54 40.100	9.9	5.7	B8e	650
HD 259431	MWC 147	06 33 05.190	+10 19 19.984	8.7	5.7	B6pe	800
MWC 297	NZ Ser	18 27 39.6	−03 49 52	9.5	3.1	O9e	450
HD 179218	MWC 614	19 11 11.254	+15 47 15.630	7.4	5.9	B9	240
HD 190073	V1295 Aql	20 03 02.510	+05 44 16.676	7.8	5.8	A2pe	280
HBC 300	V1057 Cyg	20 58 53.73	+44 15 28.4	11.6	5.7	—	575

Observations of each source were interweaved with nearby calibrator stars, chosen to exclude known binaries and variable stars. System visibility was determined based upon observations of the calibrators and models of the calibrator (e.g. size based upon multiwavelength photometry). The measured raw source visibilities were then divided by the system visibility. The resulting calibrated visibilities V_{obs}^2 are presented in Table II. Our reported visibilities are a wideband average produced synthetically from five narrowband channels. As a consistency check, sources were calibrated first relative to one calibrator, then relative to another, and the results compared to avoid problems with unknown binarity. The stellar contribution to V_{obs}^2 is subsequently removed, assuming the observed spatial distribution of emission on

the sky is the sum of an unresolved point source of known flux, and an extended circumstellar contribution. For the Herbig stars, MST estimated the fractions of the infrared emission due to the star and due to circumstellar emission at K. In Table II we list the fraction $f_{cs,K}$ of emission due to circumstellar matter, while that of the star is $f_{*,K} = 1 - f_{cs,K}$. For V1057 Cyg, we will assume all the infrared emission is circumstellar. Table II also gives $V_{cs,K}^2$ for the circumstellar contribution, where $V_{obs} = f_{*,K} + f_{cs,K} V_{cs}$. Because our program stars all have large infrared excesses, the corrections for stellar light are generally small. Upper limits to the visibility squared were determined for sources lacking fringes, based upon the sensitivity of the detection algorithm and measuring the system visibility with a nearby calibrator. Figures 1-2 show some of the measured individual visibilities V_{obs}^2 for our resolved sources.

Table II. Calibrated Visibilities and Stellar Contribution

Source	Baseline	V_{obs}^2	$f_{cs,K}$	V_{cs}^2
V594 Cas	NW	0.40 ± 0.04	0.92 ± 0.03	0.36 ± 0.04
MWC 147	NW	0.58 ± 0.03	0.84 ± 0.04	0.51 ± 0.04
MWC 147	NS	0.54 ± 0.04	0.84 ± 0.04	0.47 ± 0.05
V1057 Cyg	NW	0.63 ± 0.03	1.000	0.63 ± 0.03
MWC 297	NW,NS	< 0.2	0.84 ± 0.03	< 0.12
MWC 614	NW,NS	< 0.2	0.71 ± 0.10	< 0.05
V1295 Aql	NS	< 0.2	0.72 ± 0.03	< 0.05

Fringes were obtained for a total of four sources, although for one of these, MWC 297, there are insufficient data to produce a calibrated measurement. Thus, we treat MWC 297 as an upper limit. Based upon the observed circumstellar visibilities V_{cs}^2 , Table III gives approximate source sizes based upon a circular Gaussian and a uniform disk model:

$$V_{Gauss}^2 = \left(\exp \left\{ -\frac{\pi^2}{\ln 2} \left(\frac{\theta_{FWHM}}{2} \right)^2 \frac{B_p^2}{\lambda^2} \right\} \right)^2,$$

$$V_{UD}^2 = \left(\frac{2J_1(\pi \theta_{UD} B_p / \lambda)}{\pi \theta_{UD} B_p / \lambda} \right)^2.$$

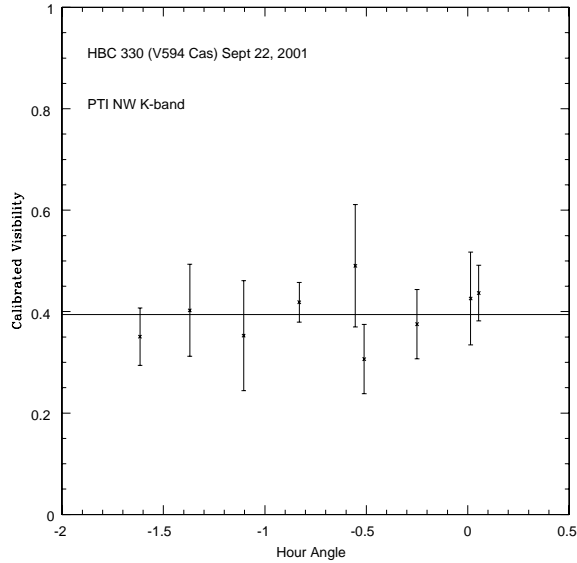


Figure 1. Calibrated Visibility of HBC 330 (V594 Cas) as a function of hour angle. The limited range of hour angles does not permit strong constraints on the source geometry.

Here $\lambda = 2.235 \mu\text{m}$, B_p the projected baseline, θ_{FWHM} is the FWHM in radians, θ_{UD} is the uniform disk diameter in radians, and J_1 is a Bessel function. The baseline lengths are 110 m in NS, and 85 m in NW. Error bars include uncertainties in our measurements and in the stellar and circumstellar fluxes, but not in the distance.

3. DISCUSSION

For our observations with the largest range of hour angles and projected baseline orientation, V1057 Cygni is consistent with a circularly symmetric source. As an FU Ori type object, there is little doubt that its infrared excess comes from a circumstellar disk and not a spherical distribution of dust. More modeling is necessary to put limits on the possible orientation of the disk. Our measurements of MWC 147 in the NS baseline are consistent with those of Akeson et al. 2000. However, the new measurement in the NW baseline is inconsistent with that of the NS baseline if the source is indeed a circularly-symmetric distribution on the sky. Because the baselines have differing orientations, the

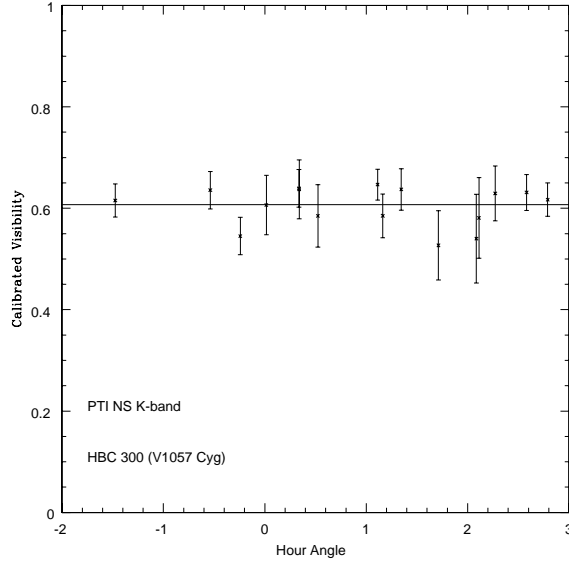


Figure 2. Calibrated visibility versus hour angle for the FU Orionis star V1057 Cyg. The lack of a significant trend suggests a circularly symmetric geometry on the sky.

difference can be accounted for by an asymmetric source distribution, such as a tilted disk. We wish to confirm the new NW measurement and perform further modeling of this source.

4. CONCLUSIONS

We have resolved three young stellar objects at milli-arc second scales, two for the first time (the Herbig Be star V594 Cas, and the FU Orionis star V1057 Cyg). Presumably we are sampling the distribution of warm dust close to the stars. However, these data alone are insufficient to fully constrain the sources, and other explanations besides circumstellar disks (e.g. a binary companion) are possible. No significant variation of the visibility is seen as a function of hour angle on the sky, suggesting a symmetric distribution on the sky. However, for MWC 147, the measurements in two different baselines suggest an asymmetric distribution, such as a tilted disk. This is consistent with recent measurements by Eisner *et al.* (2003) for a similar sample of Herbig stars, three of which appear to have disks with significant inclinations.

Table III. Source Diameters for the Gaussian and Uniform Disk Models

Source	Baseline	Gaussian		Uniform Disk	
		(mas)	(AU)	(mas)	(AU)
V594 Cas	NW	2.07 ± 0.11	1.35 ± 0.07	3.34 ± 0.16	2.17 ± 0.11
MWC 147	NW	1.63 ± 0.10	1.30 ± 0.06	2.75 ± 0.15	2.20 ± 0.12
MWC 147	NS	1.34 ± 0.09	1.07 ± 0.07	2.24 ± 0.15	1.80 ± 0.12
V1057 Cyg	NW	1.36 ± 0.07	0.78 ± 0.04	2.30 ± 0.11	1.32 ± 0.07
MWC 297	NW	> 2.9	> 1.3	> 4.6	> 2.1
MWC 614	NW	> 3.5	> 0.84	> 5.2	> 1.2
V1295 Aql	NS	> 2.7	> 0.76	> 4.0	> 1.1

This work has made use of software produced by the Michelson Science Center at the California Institute of Technology. F.P.W. is grateful to the Observatoire de la Côte d’Azur for a Poincaré fellowship, and to the NSF International Researchers Fellows Program for financial support.

References

- Akeson, R.L., Ciardi, D.R., van Belle, G.T., Creech-Eakman, M.J., & Lada, E.A. 2000, *ApJ*, 543, 313
Colavita, M.M., Wallace, J.K., Hines, B.E., *et al.* 1999, *ApJ*, 510, 505
Eisner, J.A., Lane, B.F., Akeson, R.L., Hillenbrand, L.A., & Sargent, A.I. 2003, *ApJ*, (in press)
Grasdalen, G.L. 1973, *ApJ*, 182, 781
Hillenbrand, L.A., Strom, S.E., Vrba, F.J., & Keene, J. 1992, *ApJ*, 397, 613
Malbet, F., Berger, J.-P., Colavita, M.M., *et al.* 2000, *ApJ*, 543, 313
Millan-Gabet, R., Schloerb, F.P., & Traub, W.A. 2001, *ApJ*, 546, 358